RELIABILITY of NON-DESTRUCTIVE TESTING RESULTS of WELDED JOINTS

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ABSTRACT *– One model of evaluation of reliability for non-destructive testing results is described in this paper. Performed analysis of results of radiographic and ultrasonic examination was related to two objects. In the first case the evaluation of reliability refers to evaluation of radiographic films performed by three independent NDT laboratories. In the second case completely independent radiographic and ultrasonic examinations were performed on one set of welds with extent of 100% and the other set of welds with extent of 10%. Discussion covers comparison of results for the same method and difference between results of ultrasonic and radiographic examinations of the same set of welds.*

1. INTRODUCTION

Discussion related to the reliability of result of non-destructive testing is present every day in every workshop. Workshop managers and foreman are in doubt about validity of quantity of repairs on some objects. Authorised inspectors and customer qualified representatives are in doubt about representative sample that was examined on specific object and about proper evaluation of NDT results. Also, NDT level 3 personnel think about reliability of NDT results. Formally, situation is "under control" – NDT personnel is qualified and certified in accordance with relevant standards and customers requirements, basic documentation is written in accordance with relevant standards and good practice, equipment is calibrated and organisation of NDT daily work is efficient at required technical level. However, there is still doubt present: all NDT methods are based on interpretation of one of property of examined material or object and detection of any imperfection in material is always less than 100%. This theoretical statement leads to the questions: how many imperfections were not detected or correctly interpreted and evaluated? How many unacceptable imperfections were left in delivered components or how many acceptable imperfections was repaired due of too strong evaluation of indications? Some answers were published in different technical papers that have common keyword "Round Robin Test". In the test, many participants make examination and evaluation, or only evaluation, of the same objects in controlled condition. The participants have all the time they need available for the examination. All indications were investigated and approved by appropriate non-destructive and destructive methods. However, in real situation in factory nobody can have such approach. It is not realistic to cut samples from all examined objects and to make an objective research. There shall be some different – "new approach" that can help in evaluation of reliability of NDT results. Statistical methods described in this paper can be used in real situations when there is no possibility for objective evaluation "who loses and who wins" in the poker game between workshop management, customer representatives, authorised inspectors and NDT operators.

2. METHODS

Comparison of results of non-destructive methods and statistical calculations were used for evaluation of reliability for performed examinations. Statistical calculations and comparisons of results make sense when they are applied to the set of results that contain big number of single results. Comparisons and statistical calculations can be based on single evaluations or based on acceptance of welds. Examiners that perform examination and evaluation of acceptability of specific examination can be delegated from independent NDT organizations or from the same NDT organization. Set of results shall be performed independently as much as possible.

3. RESULTS

3.1. COMPARISON OF EVALUATION FOR RADIOGRAPHIC FILMS

First case describes situation where radiographic testing (RT) was performed by independent third party NDT organisation in extent 10% in accordance with standard EN 12952-6 (Water-tube boilers and auxiliary installation – Part 6: Inspection during construction; documentation and marking of pressure parts of the boiler).

Findings of RT examinations shall be evaluated in accordance with paragraph 9.4.1.2 of the mentioned standard. This standard has acceptance criteria that are a mix of nominal, ordinary and metric levels. It means that some type of indications of imperfections that are interpreted as crack or lack of fusion is unacceptable regardless of dimension of indication. On the other side, indications of imperfections that are interpreted as gas inclusion have acceptance based on shape, dimension and concentration related to thickness of the weld. In addition, mentioned standard has not stated the level of relevant indications. In performed RT of discussed component, unacceptable imperfections were recorded and additional RT examinations were performed and finally, all welds related to the same type of weld were examined in extent 100%. Final client of boiler and also the boiler producer were worried about quality of welding work. Because of higher level of welds with unacceptable imperfections than it is expected for this type of weld and higher than it was recorded on other similar boiler components, re-evaluation of RT films by RT examiner level 3 appointed by boiler producer was performed. In his re-evaluation significant difference in comparison to the first evaluation was found but the level of welds with unacceptable imperfections was still high. Analysing all relevant data related to performed welding and RT examinations two conclusions were found: first - examined welds have systematic types of defect (gas inclusions, root concavity and poor restart) and second – RT examiner performed misinterpretation for two types of indications. To prove stated conclusions and to make a more objective discussion related to quality of welds – all RT films were sent to another third party NDT organisation for new re-interpretation. In the following table No 1 results of evaluation for 409 RT films were summarised in respect with acceptance of detected indications of imperfections.

Table 1 *Summary results of evaluation of RT films in respect with acceptance of indications*

Total number of RT films	1st NDT organisation				NDT of boiler producer				2nd NDT organisation			
	A		NA		A		NA		A		NA	
	No	%	No	%	No	%	No	%	No	%	No	%
409	308	75,31	101	24,69	356	87,04	53	12,96	364	89,00	45	11,00
A – indications on RT film evaluated as acceptable NA – indications on RT film evaluated as unacceptable												

In the second step differences in evaluation of acceptability for each radiographic film were analysed regarding each examiner. In table No 2 differences in evaluation of unacceptable indications of imperfections between all three examiners were shown. Each case describes differences in comparison for a pair of examiners. This approach is very important because it can give information about number of evaluations that coincide regarding acceptance of RT films. The sign (0) describes results that coincide. The sign (+) describes films that were evaluated by the first examiner as unacceptable but were accepted by the second examiner. The sign (-) describes films that were accepted by the first examiner but were evaluated as unacceptable by second examiner in this comparison.

Table 2 *Comparison of films with unacceptable indications for all RT examiners*

Total number of RT films	1st NDT organisation / NDT of boiler producer				1st NDT organisation / 2nd NDT organisation				NDT of boiler producer / 2nd NDT organisation			
	NA				NA				NA			
	No 1/ No2	(0)	(+)	(-)	No 1/ No2	(0)	(+)	(-)	No 1/ No2	(0)	(+)	(-)
409	101 / 53	53	48	0	101 / 45	44	57	1	53 / 45	40	13	5
NA – indications on RT film evaluated as unacceptable												

Further analysis in table No 3 shows summary results with coincidence for films with acceptable (A) and unacceptable (NA) indications for discussed welds. These results can be used for determination of weighting factor for each RT examiner based on distribution of coincidence. The assumption is that reliability of RT result in described case can be directly connected with distribution of coincidence between RT examiners.

Table 3 *Comparison of films with coincidence in evaluation (A + NA) for all RT examiners*

Total number of RT films	1st NDT organisation / NDT of boiler producer		1st NDT organisation / 2nd NDT organisation		NDT of boiler producer / 2nd NDT organisation	
	A +NA with coincidence	%	A +NA with coincidence	%	A +NA with coincidence	%
409	361	88,26	351	85,82	391	95,60
A – indications on RT film evaluated as acceptable NA – indications on RT film evaluated as unacceptable						

Finally, analysis regarding the type of imperfections that cause difference in evaluation of acceptance was performed. The results for all RT examiners were compared and shown in the table No 4. Following statement can be concluded based on these results: first - welding work can be improved - by better protection on welding place to minimise gas porosity, by welding second layer with lover heat input to avoid root concavity and by grinding each stop – start place during welding to avoid imperfections type poor restart. Second – the main difference during evaluation of acceptability for RT films was stated for indications that were evaluated as poor restart (517 – nominal level), root concavity (515 – ordinary level) and gas porosity (200 – metric level).
Corrective actions in welding work and RT film interpretation and evaluation for discussed object were performed in accordance with previous conclusions.

Table 4 *Comparison of RT films with coincidence in evaluation for different type of indications*

Designation of imperfections in accordance with EN ISO 6520-1		100	200	3041	401 and 402	504	515	517
1st NDT organisation / NDT of boiler producer	NA with coincidence	1	24	1	4	0	10	13
	NA without coincidence	1	11	3	0	1	12	20
1st NDT organisation / 2nd NDT organisation	NA with coincidence	0	18	0	3	1	11	11
	NA without coincidence	2	16	4	1	0	12	23
NDT of boiler producer / 2nd NDT organisation	NA with coincidence	0	18	0	3	0	9	10
	NA without coincidence	1	5	1	1	1	5	4
NA – indications on RT film evaluated as unacceptable								

3.2. ANALYSES OF RESULTS OF RADIOGRAPHIC AND ULTRASONIC METHOD

Analysis of results for ultrasonic (UT) and radiographic (RT) examination of butt welded joints was described in the second case. All NDT on discussed object was performed in accordance with requirements from standard EN 12952 and specific Technical requirements given by the Customer. Some sets of welded joints were examined in workshop in extent 100% by RT method and some another set of similar welded joints were also examined in extent 10% by RT method. The same situation was with UT method - some sets of welded joints were examined in the workshop in extent 100% by UT method and some another set of similar welded joints were also examined in extent 10% by UT method. RT was performed in accordance with standard EN 1435 class B and evaluation of RT films was performed in accordance with standard EN 12517 Acceptance level 1. UT was performed in accordance with standard EN 1714 examination level B and evaluation of indications was performed in accordance with standard EN 1712 acceptance level 2.

Final customer performed additional RT and UT examination to check the quality of delivered components. NDT methods (RT and UT) and extent of examination were chosen in a way regardless to the rules that were used in workshop and some groups of welds were examined with both RT and UT method. As it was expected, during examination differences between examination results performed by boiler producer and final customer were found. Further analyses of performed examinations are based on statistical methods used for comparison of results of examinations. Analyse of acceptance for welds that were examined by RT and UT in extent 100% by boiler producer and final customer was performed in the first step. Analyses were based on the weld acceptance because different RT techniques were used during re-examination in comparison to the first examination. Results of re-examination and re-evaluation for two boiler components were presented in table No 5 and 6. Given results of re-examinations were used without comments or remarks. In the first step the aim was to compare results and to interpret significance of differences.

Boiler component	Number of welds	RT - Radiographic re-examination			
		Number of welds	Extent (%) of re-examination	Number of welds with NA	Percentage (%) of welds with NA
Component No 1	336	336	100,00	12	3,57
Component No 2	336	145	43,15	7	4,83
Σ of component No 1 and No 2	672	481	71,58	19	3,95
NA – indications on RT film evaluated as unacceptable					

Table 5 *Results of RT re-examination for group of welds that were examined by boiler producer by RT in extent 100%. These welds were not re-examined by ultrasonic method.*

Table 6
Results of RT and UT re-examination for group of welds that were examined by boiler producer by UT in extent 100%.

Boiler component	Number of welds	RT - Radiographic re-examination				UT – Ultrasonic re-examination			
		Number of examined welds	Extent (%) of re-examination	Number of NA	Extent (%) of NA	Number of examined welds	Extent (%) of re-examination	Number of NA	Extent (%) of NA
No 1	48	48	100,00	6	12,50	48	100,00	0	0,00
No 2	48	32	66,66	0	0,00	32	66,66	0	0,00
Σ of No 1 and No 2	96	80	83,33	6	7,50	80	83,33	0	0,00
NA – RT and /or UT indications evaluated as unacceptable									

The case described in Table 5 shows that 96,05% of welds that were examined and re-examined by RT method were evaluated in the same way. Also, welds examined and re-examined by UT method were evaluated in the same way 100% - without any difference – see Table 6. At the same time, this group of welds was additionally re-examined by RT method – and 7,50% of welds were evaluated as unacceptable, or 92,50% of welds were accepted by RT method. Difference between RT and UT evaluation for the same welds is consequence of different interpretation of the same origin of imperfection by these two methods.

Difference of RT and UT results between boiler producer and customer were more significant for welds that were examined by RT or UT method in extent 10% as it can be visible from tables 7 and 8. It is obvious from both tables that RT method in comparison with UT method shows higher level of non-conformance with examinations performed by boiler producer.

Examinations that were based on extent of 10% are used to control the welders and welding activities with basic aim to detect, recognise and prevent systematic imperfections in welding. Results of re-examinations shall be considered in this way: re-examined welds can have random distribution of unacceptable imperfections.

Boiler component	Number of welds	RT - Radiographic re-examination				UT – Ultrasonic re-examination			
		Number of examined welds	Extent (%) of re-examination	Number of NA	Extent (%) of NA	Number of examined welds	Extent (%) of re-examination	Number of NA	Extent (%) of NA
No 1	300	291	97,00	38	13,05	227	75,66	2	0,88
No 2	300	143	47,66	13	9,09	128	42,66	6	4,68
Σ of No 1 and No 2	600	434	72,33	51	11,75	355	59,16	8	2,25
NA – RT and /or UT indications evaluated as unacceptable									

Table 7 *Results of RT and UT re-examination for group of welds that were examined by boiler producer by RT in extent 10%.*

Table 8 *Results of RT and UT re-examination for group of welds that were examined by boiler producer by UT in extent 10%.*

Boiler component	Number of welds	RT - Radiographic re-examination				UT – Ultrasonic re-examination			
		Number of examined welds	Extent (%) of re-examination	Number of NA	Extent (%) of NA	Number of examined welds	Extent (%) of re-examination	Number of NA	Extent (%) of NA
No 1	528	513	97,15	31	6,04	203	38,44	2	0,98
No 2	528	236	44,69	6	2,54	131	24,81	2	1,52
Σ of No 1 and No 2	1056	749	70,92	37	4,93	334	31,62	4	1,19
NA – RT and /or UT indications evaluated as unacceptable									

Results of re-examinations were better for welds that were examined by boiler producer in extent 10% by UT method (4,93% of NA) than re-examination results for welds examined by boiler producer in extent 10% by RT method (11,73% of NA).
Full comparison of results and statistical calculations can be performed for welds that were examined by the same NDT method in extent 100% - that means RT100% and UT100% shown in tables 5 and 6. Results of UT method do not show difference in evaluation of acceptance for examined welds so this set of results is not interesting for additional consideration. Results of RT method show differences in evaluation of acceptance for 19 welds. Table 9 shows distribution of type of imperfections for these welds. Main difference in interpretation and evaluation of acceptance was for lack of fusion and lack of penetration (type 400 of imperfection) and porosity (type 200).

Designation of imperfections in accordance with EN ISO 6520-1		100	200	3041	401 and 402	504	515	517
NDT of final client / NDT of boiler producer	Component No 1 NA without coincidence	0	4	0	7	1	1	0
	Component No 2 NA without coincidence	0	1	0	4	1	0	0
	Σ No 1 and No2 NA without coincidence	0	5	0	11	2	1	0
NA – indications on RT film evaluated as unacceptable								

Table 9 *Evaluation of welds based on RT films without coincidence in evaluation for different type of indications*

4. DISCUSSION

The cases described in the paper haven't got fully independent set of results. In the first case re-evaluation of radiographic films was performed by two independent NDT organizations, examiners did not have results of other participants, but examiners were informed that this action was re-examination. In the second case re-examinations were not performed on the component at the same time and in the same condition. Regardless of such situations each case had enough independent data for comparison and statistical calculations. It was indicated in the first case that one examiner performed evaluation of acceptance of welds stronger than it is required by the standard. This situation can be understood because examiners usually do not like any comment made by the supervisor and they evaluate any suspicious indication as unacceptable without second opinion or without additional examination.
It is indicated in the second case that realistic comparison of results can be performed for set of results given by the same NDT method. Differences in acceptance of welds found for RT100% and UT100% indicate that examination and evaluation of acceptability for this set of welds was performed at the same level. Differences in acceptance of welds found for RT10% and UT10% indicate that one quantity of randomly distributed imperfections were missed in non-examined welds. Initial sample that represented 10% of welds was selected independently for the first and for the second examination. In these sets of welds there was very low quantity of welds that can be included in set for comparison and statistical calculation. Results of examination and re-examination can be used for evaluation of trend only. To improve discussion related to second case it would be helpful to include third independent examiner for re-evaluating all produced results.

5. CONCLUSIONS

NDT methods are based on interpretation of indications. Acceptability for welds is based on mixed nominal, ordinary and metric criteria. Consequently, NDT hasn't got metric behaviour and it is not realistic to compare single results. Comparison and statistical calculations can be used for identification of trends in examination and evaluation of acceptability of welds. This approach gives better understanding of examination process, improves reliability of NDT results and leads to proper corrective actions without using expensive samples that have objective description of incorporated imperfections.
It is obvious that improved reliability does not mean that differences between examiners will disappear but distribution of differences in examination and evaluation of indications will be in a narrow area.

6. REFERENCES

[1] F. Fücsök, C. Müller, M. Scharmach, MEASURING OF THE RELIABILITY OF NDE, The 8th International Confernce of the Slovenian Society for Non-Destructive Testing, Portorož 2005